Appendix F

Health Risk Assessment Estimation Methods

F.1. Risk Assessment Estimation Methods

This appendix describes the methods used to estimate the potential cancer and non-cancer risk from thermal metal spraying operations. These risk estimates were used to support the development of the proposed Thermal Spraying Airborne Toxic Control Measure (ATCM).

The risk estimates were based on air dispersion modeling results from four actual facilities in the San Diego County Air Pollution Control District (SDAPCD). The modeling results from these four facilities were used to estimate health risks from all of the thermal spraying facilities in California that use chromium or nickel containing compounds.

Exposures were estimated at varying receptor distances, including the point of maximum impact (PMI), as determined by air dispersion modeling at the actual facilities. The estimated risk levels are intended to provide an estimate of the potential health risks near thermal spraying facilities. Actual risks will vary due to site-specific parameters, including material usage, exhaust flowrate, control device efficiency, and distance to receptors.

The risk assessment was conducted using the following approach:

Step 1 - Hazard Identification	The risk assessor determines if a hazard exists, and if so, identifies the pollutant(s) and the type of effect, such as cancer or respiratory effects.
Step 2 - Dose-Response Assessment	The risk assessor characterizes the relationship between a person's exposure to a pollutant and the occurrence of an adverse health effect.
Step 3 - Exposure Assessment	The risk assessor estimates the extent of public exposure by looking at who is likely to be exposed, how exposure will occur, and the magnitude of exposure (e.g., the airborne concentration of a pollutant.)
Step 4 - Risk Characterization	The risk assessor combines airborne pollutant concentrations with cancer potency factors (for cancer risk) and reference exposure levels (for non-cancer effects) to quantify the potential cancer risk and non-cancer health impacts.

The methods used in this risk assessment are consistent with the Tier 1 analysis, presented in the OEHHA Air Toxics "Hot Spots" Program Risk Assessment Guidelines, the Air Toxics Hot Spots Program Guidance Manual for Preparation of Health Risk Assessments (OEHHA, 2003). Health and exposure information was obtained from the following references:

(1) The OEHHA Air Toxics "Hot Spots" Program Risk Assessment Guidelines, Part I, The Determination of Acute RELs for Airborne Toxicants (OEHHA, 1999);

(2) The OEHHA Air Toxics “Hot Spots” Program Risk Assessment Guidelines, Part II, Technical Support Document for Describing Available Cancer Potency Factors (OEHHA, 2002);
(3) The OEHHA Air Toxics Hot Spots Program Risk Assessment Guidelines, Part III, Technical Support Document for the Determination of Noncancer Chronic Reference Exposure Levels (OEHHA, 2000a);
(4) The OEHHA Air Toxics Hot Spots Program Risk Assessment Guidelines, Part IV, Technical Support Document for Exposure Analysis and Stochastic Analysis (OEHHA, 2000); and
(5) “Recommended Interim Risk Management Policy for Inhalation–Based Residential Cancer Risk” (ARB, 2003a)

Table F-1 summarizes the key parameters that were used when conducting the air dispersion modeling and the health risk assessment.

Table F-1:
Key Parameters for Air Dispersion Modeling and Health Risk Assessment

Air Dispersion Model:	U.S. EPA, Industrial Source Complex Short Term (ISCST3), Version 02035
Source Type:	Volume and Point
Dispersion Setting:	Urban
Receptor Height:	1.2 meters
Stack Information (Point Sources):	
Stack Diameters	0.55, 0.81, and 0.88 meters
Stack Heights	5.5, 10.7, and 13.7 meters
Stack Temperatures	300, 294, and 293 degrees Kelvin
Stack Exhaust Velocities	24, 19, and 13 meters/second
Volume Source Information:	
Release Height	1.8 meters
Lateral Dimension	9.9 meters
Vertical Dimension	2.3 meters
Meteorological Data:	Los Angeles area – Vernon, West LA San Francisco Bay area – San Francisco Airport San Diego area – Barrio Logan, Miramar Naval Air Station, Lindbergh Airport
Exposure Duration, Exposure Frequency	70 yrs, 350 days/year
Adult Daily Breathing Rates:	393 liters/kg body weight-day (high-end) 302 liters/kg body weight-day (80th percentile) 271 liters/kg body weight-day (mean)
Adult Body Weight:	70 kg
Cancer Inhalation Potency Factors:	Hexavalent Chromium – 510 $(mg/kg\text{-}day)^{-1}$ Nickel – 0.91 $(mg/kg\text{-}day)^{-1}$
Non-Cancer Acute Reference Exposure Levels (RELs) – Inhalation:	Hexavalent Chromium – not established Nickel – 6.0 ug/m^3
Non-Cancer Chronic RELs - Inhalation:	Hexavalent Chromium – 0.20 ug/m^3 Nickel – 0.05 ug/m^3
Non-Cancer Chronic RELs - Oral:	Hexavalent Chromium – 0.02 mg/kg-day Nickel – 0.05 mg/kg-day

F.2. Multi-Pathway Health Risk Assessment

In evaluating the potential health effects of a pollutant, it is important to identify the different routes by which an individual could be exposed to the pollutant. The appropriate pathways to include in a HRA are dependent on the specific toxic air pollutant that a person (receptor) is exposed to, and can include inhalation, dermal exposure, and the ingestion of soil, water, crops, fish, meat, milk, and eggs. However, hexavalent chromium and nickel are only considered to be carcinogenic via inhalation exposure (OEHHA, 2003.) In addition, our analysis indicates that the inhalation pathway and the potential impacts on the respiratory endpoint would present the most significant non-cancer chronic health impacts. Therefore, this health risk assessment focused upon the impacts of exposure to hexavalent chromium and nickel via the inhalation pathway.

F.3. Hazard Identification

Thermal spraying is a process in which metals are deposited in a molten or nearly molten condition to form a coating. The process generates air emissions of metal fumes and dust. These emissions can include chemicals that are classified as toxic air contaminants (e.g. hexavalent chromium and nickel.) The primary hazard from thermal spraying is related to air emissions of hexavalent chromium, followed by nickel.

Both hexavalent chromium and nickel are classified as carcinogens. Exposure to hexavalent chromium may cause lung and nasal cancers, respiratory irritation, severe nasal and skin ulcerations and lesions, perforation in the nasal septum, liver and kidney failure and birth defects. Exposure to nickel may cause lung and nasal cancers, allergic sensitization, asthma, and other respiratory ailments. It is possible to have significant potential acute health impacts from nickel, even though the potential for cancer health impacts from nickel is very low.

In 2003, the Air Resources Board (ARB) staff conducted a survey of thermal spraying materials that were sold in California during 2002. The survey focused on gathering data for products that contained toxic air contaminants. It also gathered data on products that contained copper, due to potential acute health risks. Based on the survey results, the primary chemicals of concern were: Hexavalent chromium, nickel, and cobalt. Cobalt has not yet been assigned a cancer potency factor or any non-cancer health factor; therefore, cobalt is not included in the risk assessment calculations for this report. Hexavalent chromium and nickel are the two chemicals that were evaluated for potential cancer and non-cancer health impacts.

F.4. Dose Response Assessment

OEHHA develops dose-response factors to characterize the relationship between a person’s exposure to a pollutant and the occurrence of an adverse health effect. A cancer potency factor is used when estimating potential cancer risks and reference exposure levels (RELs) are used to assess potential non-cancer health impacts (OEHHA, 1999; OEHHA, 2002; OEHHA, 2003).

Table F-2 contains inhalation cancer potency factors, non-cancer RELs, and non-cancer toxicological endpoints for hexavalent chromium and nickel. No acute REL has been established for hexavalent chromium. Therefore, we did not estimate acute health impacts from hexavalent chromium.

Table F-2:
Health Effects Values Used in Health Risk Assessment

	Hexavalent Chromium	**Nickel**
Cancer Inhalation Potency Factor (mg/kg-day)$^{-1}$	510	0.91
Non-Cancer Reference Exposure Levels (ug/m^3)		
Acute - Inhalation	N/A	6.0
Chronic – Inhalation	0.20	0.05
Chronic - Oral	0.02	0.05
Toxicological Endpoints		
Acute - Inhalation	N/A	Immune System and Respiratory System
Chronic – Inhalation	Respiratory system	Hematopoietic System and Respiratory System
Chronic - Oral	Hematologic	Alimentary

(OEHHA, 2003)

F.5. Exposure Assessment

Hexavalent chromium and nickel are only considered to be carcinogenic when exposure occurs by the inhalation route (OEHHA, 2003.) In addition, non-cancer chronic health impacts can occur through multiple pathways, including inhalation, soil ingestion, and dermal (skin) exposure. Non-cancer acute health impacts occur by inhalation only.

For thermal spraying activities, the persons that are most likely to be exposed include off-site workers located near the facility and nearby residents. On-site workers could be impacted by the emissions; however, they are not included in this health risk assessment (HRA) because Cal/OSHA has jurisdiction over on-site workers.

The magnitude of exposure was assessed through the following process. ARB staff conducted air dispersion modeling to provide downwind airborne concentrations of hexavalent chromium and nickel in the ambient air. The downwind concentration is a function of the quantity of emissions, release parameters at the source, and appropriate meteorological conditions. Results of the air dispersion modeling are detailed in Appendix E.

Air dispersion modeling was conducted using the U.S. EPA, Industrial Source Complex Short Term (Version 02035) air dispersion model (ISCST3 model). The ISCST3 model estimates concentrations at specific locations around each facility, directly caused by each facility's emissions. Facility operating parameters are provided in Table F-3 and exhaust parameters are contained in Table F-4.

Table F-3:
Air Dispersion Modeling - Facility Parameters

Facility	Stack Height (m)	Stack Diameter (m)	Stack Gas Temp. (°K)	Stack Gas Velocity (m/s)	Hours When Emissions May Occur		Hexavalent Chromium Emissions	
					Hours Per Day	**Beginning At**	**Average Rate (g/s)**	**Annual (lbs/yr)**
1	1.8	0.3	-*	-*	9	8 am	8.71E-07	2.27E-02
2	5.5	0.549	299.8	23.96	6	6 am	1.64E-08	2.85E-04
3	10.7	0.811	294.3	19.01	24	-	4.00E-08	2.78E-03
4	13.7	0.884	293.2	12.92	9	8 am	4.23E-09	1.10E-04

* Volume Source (i.e., no exhaust stack)

Glossary of Acronyms:

(m) = Meters
(°K) = Degrees Kelvin
(m/s) = Meters Per Second
(g/s) = Grams Per Second
(lbs/yr) = Pounds Per Year

Table F-4:
Air Dispersion Modeling – Exhaust Parameters

Facility	Type of Source	Exhaust Parameters		
1	Volume	H = 1.8 m	Syo = 9.9 m	Szo = 2.3 m
2	Point	Hs = 5.5 m	Ds = 0.55 m	Vs = 23.96 m/s
3	Point	Hs = 10.7 m	Ds = 0.81 m	Vs = 19.01 m/s
4	Point	Hs = 13.7 m	Ds = 0.88 m	Vs = 12.92 m/s

H = Source Release Height, meters
Syo = Initial Lateral Dimension of the Volume, meters
Szo = Initial Vertical Dimension of the Volume, meters
Hs = Stack Height, meters
Ds = Stack Diameter, meters
Vs = Stack Gas Velocity, meters/second

Facility #1 was modeled as a volume source, because emissions were exhausted through a horizontal vent at breathing zone height. Volume sources can result in higher health risks, because the pollutant discharge is more concentrated near the breathing zone, rather than being dispersed through a vertical exhaust stack. Facilities #2, #3, and #4 were modeled as point sources with vertical exhaust stacks. All four facilities were equipped with air pollution control devices.

The majority of the thermal spraying facilities in California are located in three areas: Los Angeles, San Diego, and the San Francisco Bay Area. This conclusion is based on the results of ARB's 2004 Thermal Spraying Facility Survey, ARB's 2003 Thermal Spraying Materials Survey, and air permit data from local districts (ARB, 2004c; ARB, 2004b). Meteorological data from these three areas were used to conduct air dispersion modeling for all four facilities. The modeling analyzed airborne concentrations for potential receptor distances that ranged from 30 to 5000 meters (or 100 – 16,400 feet) away from the thermal spraying facilities. The detailed results from this modeling are contained in Appendix E.

Air dispersion modeling results are expressed as an air concentration or in terms of (CHI/Q) for each receptor distance. (CHI/Q is the modeled downwind concentration based on an emission rate of one gram per second.) Table F-5 lists the (CHI/Q) values that resulted from the air dispersion modeling. These values represent the high-end results from the air dispersion modeling. For each of the four actual facilities, we evaluated results from the three meteorological areas and selected the set of results from the one meteorological area that yielded the highest annual average concentrations. The table contains the annual average (CHI/Q) values and the corresponding maximum 1-hour (CHI/Q) values for the selected meteorological areas.

Table F-5:
Facilities –CHI/Q Values (ug/m^3)/(g/s)

Facility	**Receptor Distance from source** (meters)									**Max. 1-Hr CHI/Q**
	30	**40**	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**	
1	321.50	220.16	156.63	48.54	13.51	2.28	0.59	0.20	0.07	5671
2	11.37	12.78	12.07	6.33	2.41	0.57	0.18	0.06	0.02	708
3	19.60	29.36	37.40	31.48	15.06	4.00	1.33	0.44	0.11	453
4	N/A	43.62	47.63	32.68	12.04	2.20	0.57	0.19	0.07	333

N/A: Plume has yet to touch down or the receptor is near the building wake effects.

The ARB 2004 Thermal Spraying Facility Survey gathered data on the locations of active thermal spraying businesses in California. ARB staff used this location data and local zoning information to estimate the distance from a business to the nearest sensitive receptor. Sensitive receptors that were identified included schools, hospitals, and residential areas. Most (>70%) thermal spraying facilities are located more than 100 meters (or 330 feet) from sensitive receptors. The (CHI/Q) values and corresponding health risks decrease significantly beyond 100 meters. Figures F-1 and F-2 illustrate the number of facilities at each receptor distance and the corresponding (CHI/Q) value.

Figure F-1:
Point Sources - Number of Facilities in Each Receptor Distance Range & Corresponding (CHI/Q)

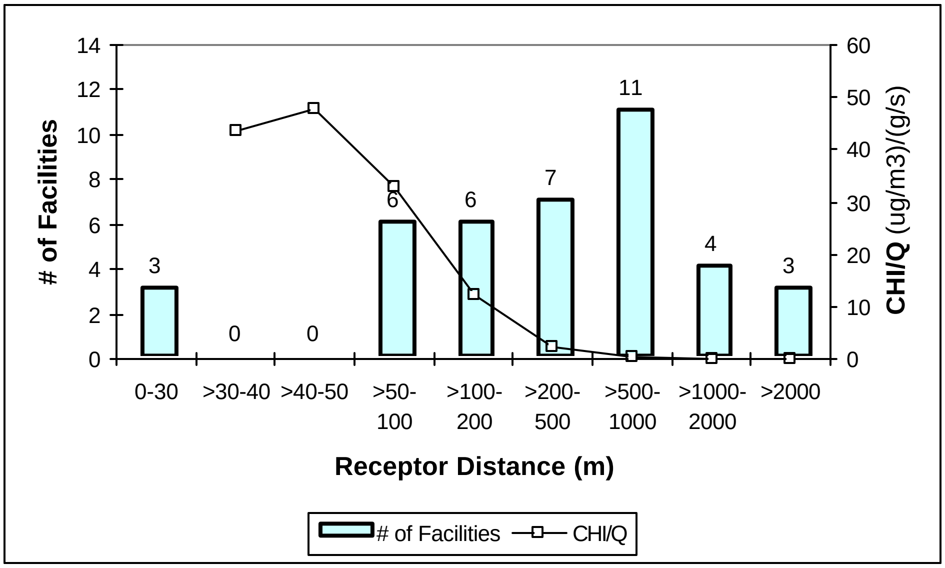
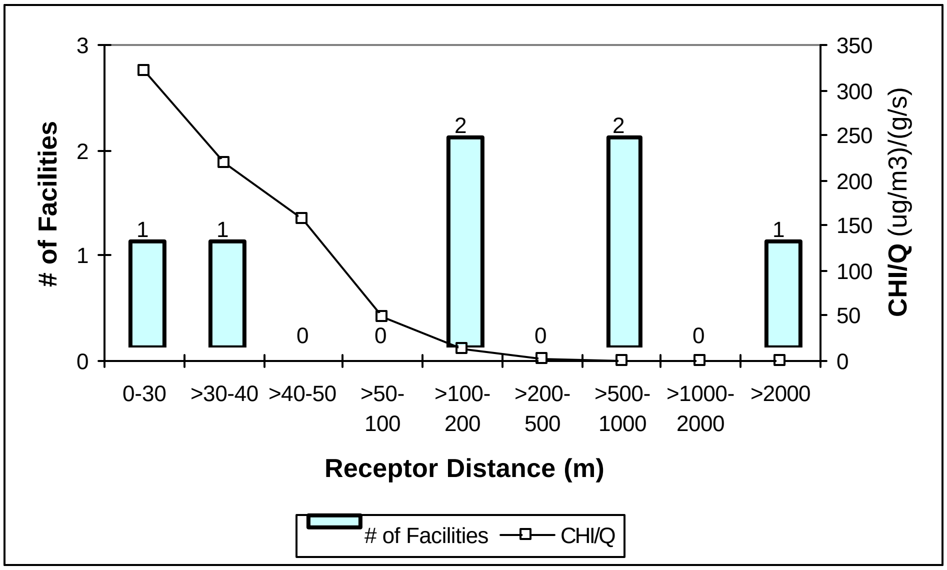


Figure F-2:
Volume Sources - Number of Facilities in Each Receptor Distance Range & Corresponding (CHI/Q)



Different thermal spraying processes can cause different emission rates. The health risk assessment included an evaluation of the health risks associated with emissions from the following processes: flame spraying; plasma spraying; and twin-wire electric arc. These processes were selected because they were the top three most common types identified in ARB's 2004 Thermal Spraying Facility Survey.

Ground-level concentrations (GLCs) for pollutants were calculated using the following equation and the [CHI/Q] values in Table F-5.

Eqn. F.1.: $[GLC] = [CHI/Q]*[Q]$ (OEHHA, 2003)

where
GLC = Ground Level Concentration of Pollutant, ug/m^3
CHI/Q = Modeled Downwind Air Concentration of Pollutant, $(ug/m^3)/(g/s)$

$$Q = \text{Average Emission Rate of Pollutant (g/s)} = \frac{[\text{Annual Emissions, lb/yr}]*453.59\ \text{grams/lb}]}{[365\ \text{days/yr}]*[\text{Operating Hours, hrs/day}]*[3600\ \text{sec/hr}]}$$

Equation F.1 allowed us to evaluate how different emission rates could impact the concentration of pollutants in the air. Ground level concentrations were estimated for each of the three thermal spraying processes, at each of the generic facilities. The calculated GLCs represent a conservative estimate of the pollutant concentrations at each facility.

F.6. Cancer Risk Characterization

Cancer risk characterization involves calculating the potential health risks, based on exposure and cancer potency factors. We evaluated the cancer and non-cancer health impacts and found that the potential cancer health impacts were more significant than non-cancer impacts. Therefore, the following section focuses on cancer risk thresholds and a correlation to emission rates. Section F.6 contains a discussion of non-cancer health impacts.

For the purposes of this risk assessment, we determined the threshold emission rates that would likely result in potential cancer risk levels of up to 1 in a million and up to 10 in a million.

To estimate the cancer risk from inhalation exposure, we used the following equations (OEHHA, 2003):

Eqn. F.2: $[\text{Cancer Risk}] = [\text{Inhalation Dose, mg/kg-day}]*[\text{Cancer Potency, }(\text{mg/kg-day})^{-1}]$

Note: To convert this to chances per million, multiply the cancer risk by 10^6.

Eqn. F.3:

$$[\text{Inhalation Dose, mg/kg-day}] = \frac{[C_{air}]*[DBR]*[A]*[EF]*[ED]*[10^{-6}]}{AT}$$

where

		Definitions	**Values**
C_{air}	=	Concentration in Air, ug/m^3	Based on air dispersion modeling or calculated GLC
DBR	=	Adult Daily Breathing Rate, L/kg body weight-day	Defaults = 393 (70-yr exposure, high-end) = 302 (70-yr exposure, 80th percentile) = 271 (70-yr exposure, mean)*
A	=	Inhalation Absorption Factor, unitless	Default = 1
EF	=	Exposure Frequency, days/year	Default = 350
ED	=	Exposure Duration, years	Default = 70
AT	=	Averaging Time Period for Exposure, days	Default = 25,550 (70 yrs * 365 days/year)
10^{-6}	=	Micrograms to Milligrams conversion and Liters to Cubic Meters conversion	

For each of the facilities listed in Table F-3, we estimated the annual emissions of hexavalent chromium that would likely result in potential cancer risks of up to 1 in a million and up to 10 in a million. Staff also calculated the usage quantities of chromium that corresponded to these emission levels. Emissions were estimated using emission factors, as discussed in Appendix C and Appendix D.

Equations F.1, F.2, and F.3 are generally used to evaluate the risk based on a given set of operating parameters. However, these equations can also be used to determine the emission rates that are likely to result in potential cancer risks at a given level. As shown below, Equations F.1, F.2, and F.3 can be reorganized to calculate the emission rates that that would likely result in potential cancer risks of up to 1 in a million and up to 10 in a million.

$$[\text{Inhalation Dose}] = \frac{[C_{air}]*[DBR]*[A]*[EF]*[ED]*[10^{-6}]}{AT}$$

$$[\text{Cancer Risk, chances per million}] = [\text{Inhalation Dose}]*[\text{Cancer Potency}]*10^{6}$$

Therefore, the inhalation dose that would likely result in a potential cancer risk at a given level is –

Eqn. F.4: $$[\text{Inhalation Dose @ risk level, mg/kg/day}] = \frac{[\text{Cancer Risk}]}{[\text{Cancer Potency}]*10^{6}}$$

The airborne concentration (C_{air}) that would likely result in a potential cancer risk at a given level is –

Eqn. F.5: $$[C_{air}\text{ @ risk level, ug/m}^{3}] = \frac{[\text{Inhalation Dose @ risk level, mg/kg/day}]*[AT][10^{6}]}{[DBR]*[A]*[EF]*[ED]}$$

$[C_{air}] = [CHI/Q]*[Q]$ and
$[Q] = [C_{air}]/[CHI/Q]$

Therefore, the emission rate (Q) that would likely result in a potential cancer risk at a given level is –

Eqn. F.6:

$$[Q,\ \text{Emission Rate @ risk level, g/s}] = \frac{[\text{Cair @ risk level}]}{[\text{CHI/Q}]}$$

The annual emissions level that would likely result in a potential cancer risk at a given level is –

Eqn. F.7:

$$[\text{Annual Emissions @ risk level, lb/yr}] = \frac{[\text{Q @ risk level, g/s}]*[\text{Operating Hours, hrs/yr}]*[3600\ \text{sec/hr}]}{[453.59\ \text{g/lb}]}$$

"Operating Hours" are the annual hours of operation that were used in the air dispersion modeling and which correspond to the (CHI/Q) value.

For example, to determine the hexavalent chromium emission rate that would likely result in a potential cancer risk that does not exceed 10 in a million –

Assumptions:

- Point Source
- Receptor distance = 50 meters (164 feet)
- CHI/Q (from air dispersion modeling) = 47.63 (ug/m^3)/(g/s)
- Operating Hours (from air dispersion modeling) = 9 hrs/day, 365 days/yr
- Daily Breathing Rate = 393 L/kg body weight-day), 95th percentile value
- Cancer Potency Factor, Hexavalent Chromium = 510 (mg/kg-day)$^{-1}$

The inhalation dose that would likely result in a potential cancer risk up to 10 in a million is –

$$[\text{Inhalation Dose @ 10 in a million risk, mg/kg/day}] = \frac{[10]}{[510]*10^6} = 1.96E\text{-}08\ \text{mg/kg/day}$$

The airborne concentration that would likely result in a potential cancer risk that does not exceed 10 in a million is –

$$[\text{Cair @ risk level, ug/m3}] = \frac{[1.96E\text{-}08\ \text{mg/kg/day}]*[25550\ \text{days}]*[10^6]}{[393\ \text{l/kg-day}]*[1]*[350\ \text{days/yr}]*[70\ \text{yrs}]} = 5.20E\text{-}05\ \text{ug/m}^3$$

The emission rate (Q) that that would likely result in a potential cancer risk that does not exceed 10 in a million is –

$$[Q,\ \text{Emission Rate @ risk level, g/s}] = \frac{[5.20E\text{-}05\ \text{ug/m}^3]}{[47.63\ (\text{ug/m}^3)/(\text{g/s})]} = 1.09E\text{-}06\ \text{g/s}$$

To calculate annual emissions that would likely result in a potential cancer risk that does not exceed 10 in a million –

$$[\text{Annual Emissions @ risk level, lb/yr}] = \frac{[1.09E\text{-}06\ \text{g/s}]*[3285\ \text{hrs/yr}]*[3600\ \text{sec/hr}] = 0.028\ \text{lb/yr}}{[453.59\ \text{g/lb}]}$$

Table F-6 summarizes the minimum emission rates that that would likely result in a potential cancer risk of up to 10 in a million for hexavalent chromium. Table F-5 represents a conservative scenario for potential cancer risks that corresponds to the point of maximum impact for health effects. Emissions from facilities that are located at different receptor distances may result in lower potential cancer risk estimates.

Table F-6:
Minimum Cr^{+6} Emission Rates That Would Likely Result in Potential Cancer Risks Up to 10 in a Million

Facility	Type of Source	Receptor Distance Where Minimum Occurs (m)	Minimum Emission Rate (lbs Cr^{+6}/yr)	
			High-End *	**Mean ***
1	Volume Source	30	0.004	0.006
4	Point Source	50	0.028	0.041

* The potential cancer risk was calculated using the following daily breathing rates (DBRs):

High-End (95th percentile)	=	393 L/kg body weight-day
Mean (65th percentile)	=	271 L/kg body weight-day

Table F-7:
Minimum Nickel Emission Rates That Would Likely Result in Potential Cancer Risks Up to 10 in a Million

Facility	Type of Source	Receptor Distance Where Minimum Occurs (m)	Minimum Emission Rate (lbs Ni/yr)	
			High-End	**Mean**
1	Volume Source	30	2	3
4	Point Source	50	16	23

If a facility has performed a stack test, they may be able to use the results of that stack test to determine whether their annual emissions exceed the levels in Tables F-6 and F-7. For facilities that have not performed a stack test, they can calculate their emissions using the emission calculation methods described in Appendix C and Appendix D.

Figures F-3 and F-4 illustrate the potential cancer risk ranges for set emission levels and different receptor distances. The shaded areas indicate potential cancer risk ranges that are less than or equal to 10 in a million, based on the 95th percentile breathing rate. Both figures show that there are two situations which would likely result in potential cancer risks that do not exceed 10 in a million:

(1) Limiting hexavalent chromium emissions to 0.01 lbs Cr^{+6}/yr (for point sources) and 0.004 lbs Cr^{+6}/yr (for volume sources); or
(2) Locating thermal spraying facilities at least 1640 feet (500 meters) from sensitive receptors.

Figure F-3: Hexavalent Chromium - Estimated Risk Range vs. Receptor Distance for Point Sources

Emissions (lbs Cr^{+6}/yr)								
0.004	A	A	A	A	A	A	A	A
0.01	A	A	A	A	A	A	A	A
0.05	B	B	B	A	A	A	A	A
0.1	B	B	B	A	A	A	A	A
0.5	C	C	C	B	A	A	A	A
	40	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**
	Receptor Distance (meters)							

KEY A: ≤ 10 in a million
B: >10 and ≤ 100 in a million
C: >100 in a million

Figure F-4: Hexavalent Chromium – Estimated Risk Range vs. Receptor Distance for Volume Sources

Emissions (lbs Cr^{+6}/yr)									
0.004	A	A	A	A	A	A	A	A	A
0.01	B	B	B	A	A	A	A	A	A
0.05	B	B	B	B	A	A	A	A	A
0.1	C	C	C	B	A	A	A	A	A
0.5	C	C	C	C	B	A	A	A	A
	30	**40**	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**
	Receptor Distance (meters)								

KEY A: ≤ 10 in a million
B: >10 and ≤ 100 in a million
C: >100 in a million

Figures F-5 and F-6 illustrate the potential cancer risk ranges for set emission levels of nickel at different receptor distances. Figures F-5 and F-6 are based on nickel emission levels that are much higher than the hexavalent chromium emission levels shown in Figures F-3 and F-4. Even though the nickel emissions are higher than the emissions of hexavalent chromium, the potential health risks from nickel are much lower than the potential risks from hexavalent chromium. This is due to the fact that nickel is less toxic than hexavalent chromium.

Figure F-5: Nickel – Estimated Risk Range vs. Receptor Distance for Point Sources

Emissions (lbs Ni/yr)								
2	A	A	A	A	A	A	A	A
5	A	A	A	A	A	A	A	A
10	A	A	A	A	A	A	A	A
50	B	B	B	A	A	A	A	A
100	B	B	B	B	A	A	A	A
	40	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**
	Receptor Distance (meters)							

KEY A: ≤ 10 in a million
B: >10 and ≤ 100 in a million

Figure F-6: Nickel - Estimated Risk Range vs. Receptor Distance for Volume Sources

Emissions (lbs Ni/yr)									
2	A	A	A	A	A	A	A	A	A
5	B	B	B	A	A	A	A	A	A
10	B	B	B	A	A	A	A	A	A
50	C	C	C	B	A	A	A	A	A
100	C	C	C	B	B	A	A	A	A
	30	**40**	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**
	Receptor Distance (meters)								

KEY A: ≤ 10 in a million
B: >10 and ≤ 100 in a million
C: >100 in a million

The ARB 2004 Thermal Spraying Facility Survey gathered data on the total annual material usage quantities and the types of toxic air contaminants contained in thermal spraying materials. These data were used to estimate the potential health risks for each facility. In addition, some facilities provided more detailed information on material usage and product composition. If detailed product composition data was not available, we used data from the ARB 2003 Thermal Spraying Manufacturer Survey to estimate the weight percentages of chromium and nickel contained in the thermal spraying materials. According to the Manufacturer Survey, thermal spraying powders contained 30.7% of chromium and 54.1% nickel, while wires contained 20.1% chromium and 53.1% nickel, based on sales-weighted averages. When estimating emissions for individual facilities, it was assumed that all of the reported material contained 30.7% of chromium and 54.1% nickel, to be conservative. Table F-8 summarizes the maximum estimated cancer risks from hexavalent chromium emitted by small, medium, and large thermal spraying facilities. Small facilities are those that reported an annual usage quantity of 500 lbs/yr or less for thermal spraying materials. Medium facilities reported annual usage quantities between 500 – 5000 lbs/yr. Large facilities reported more than 5,000 lbs/yr of thermal spraying materials.

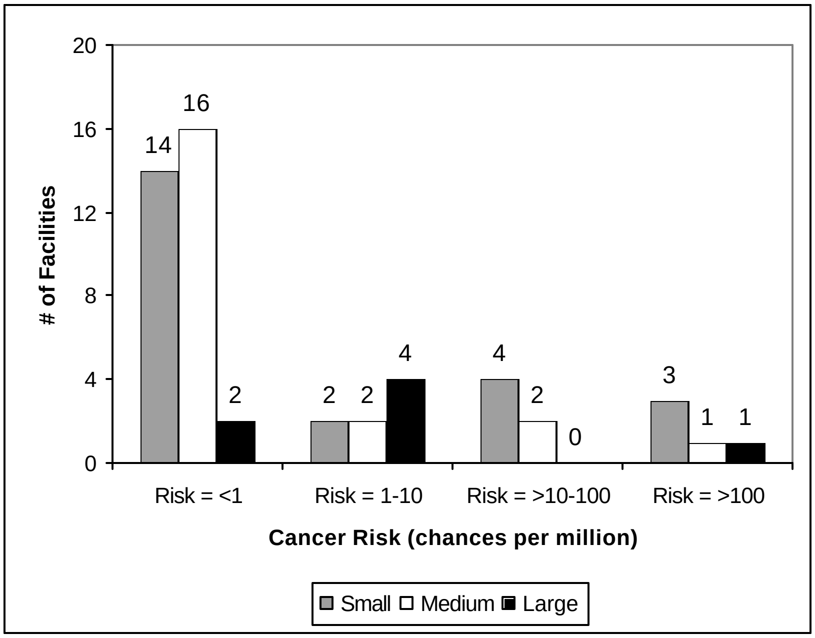
Table F-8:
Distribution of Maximum Potential Cancer Risks from Thermal Spraying - Hexavalent Chromium

Maximum Potential Cancer Risk	Small (500 lbs/yr or less of total material usage)	Medium (>500 – 5,000 lbs/yr of total material usage)	Large (>5,000 lbs/yr of total material usage)
Risk = <1	14	16	2
Risk = 1-10	2	2	4
Risk = >10-100	4	2	0
Risk = >100	3	1	1
Totals:	**23**	**21**	**7**

1. High-end daily breathing rate of 393 L/kg body weight-day was used to estimate cancer risk.
2. Assume that thermal spraying materials contain the sales-weighted average value of chromium (30.7 wt.%), as identified in ARB 2003 Thermal Spraying Manufacturer Survey, if detailed facility usage data was not available.
3. Average emission factors were established for each facility, based on the reported thermal spraying processes and reported control devices.

Figure F-7 illustrates the distribution of maximum potential cancer risks from thermal spraying hexavalent chromium emissions, based on facility size (i.e. the quantity of thermal spraying materials used annually.) This figure includes 21 thermal spraying facilities that pose a health risk <1 because they do not use materials containing chromium.

Figure F-7:
Maximum Estimated Potential Cancer Risk from Hexavalent Chromium Based on Facility Size



Small - 500 lbs/yr or less; Medium - > 500 - 5000 lbs/yr; Large - > 5000 lbs/yr

Table F-9 summarizes the maximum potential cancer risks from nickel emitted by thermal spraying facilities.

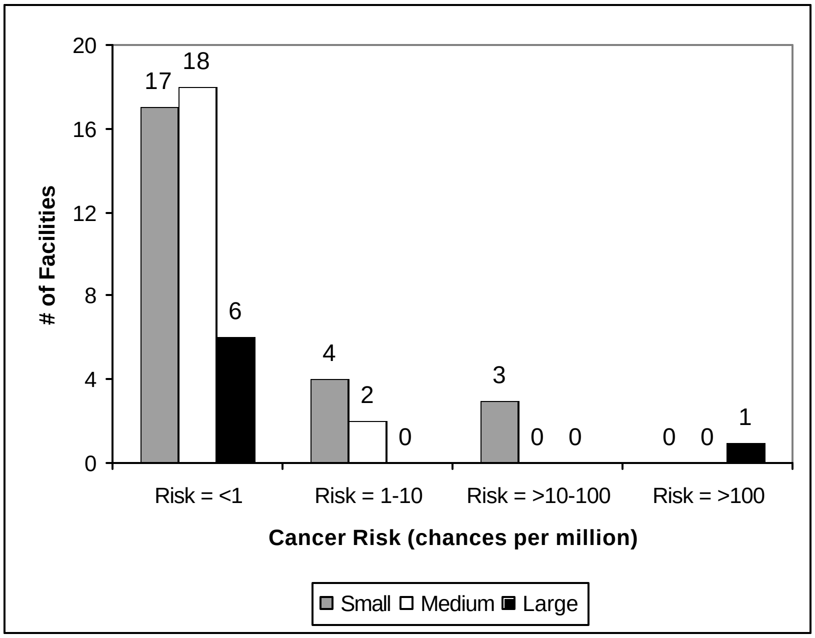
Table F-9:
Distribution of Maximum Potential Cancer Risks from Thermal Spraying – Nickel

Maximum Potential Cancer Risk	Small (500 lbs/yr or less of total material usage)	Medium (500 – 5,000 lbs/yr of total material usage)	Large (>5,000 lbs/yr of total material usage)
Risk = <1	17	18	6
Risk = 1-10	4	2	0
Risk = >10-100	3	0	0
Risk = >100	0	0	1
Totals:	**24**	**20**	**7**

1. High-end daily breathing rate of 393 L/kg body weight-day was used to estimate cancer risk.
2. Assume that thermal spraying materials contain the sales-weighted average values of nickel (54.1 wt.%), as identified in ARB 2003 Thermal Spraying Manufacturer Survey.
3. Average emission factors were established for each facility, based on the reported thermal spraying processes and reported control devices.

Figure F-8 illustrates the distribution of maximum potential cancer risks from thermal spraying nickel emissions, based on facility size (i.e. the quantity of thermal spraying materials used annually). This figure includes 16 thermal spraying facilities that pose a health risk <1 because they do not use materials containing nickel.

Figure F-8:
Maximum Estimated Potential Cancer Risk from Nickel Based on Facility Size



Small - 500 lbs/yr or less; Medium - > 500 - 5000 lbs/yr; Large - > 5000 lbs/yr

Potential health impacts are based on pollutant emission rates, but facilities generally track material usage, rather than emissions. Therefore, we've also estimated the minimum chromium usage rates that would likely result in potential cancer risks that do not exceed 10 in a million. Facilities could then compare their chromium usage rates with these levels to determine whether their operations might present a potential risk of approximately 10 in a million. To calculate the quantity of chromium used, facilities would need to identify the percentage of total chromium that is contained in their thermal spraying materials and then multiply that percentage by the quantity of material used. Table F-10 lists the minimum annual usage quantities for total chromium that would likely result in potential cancer risks that do not exceed 10 in a million for different processes and control devices. These values are based on the emission calculation methods described in Appendix C and Appendix D.

Table F-10:
Minimum Usage Rates That Would Likely Result in Potential Cancer Risks Up to 10 in a Million *

Type of Source / Control Efficiency	**Receptor Distance Where Minimum Occurs (m)**	**Minimum Chromium Usage (lbs Cr/yr)**		
		Flame Spraying	**Plasma Spraying**	**Twin-Wire Electric Arc**
Volume Source	30			
0%		1	**<1**	1
90%		4	**1**	6
99%		68	**2**	61
Point Source	50			
0%		5	**2**	4
90%		24	**4**	41
99%		459	**11**	409

*Cancer risk estimates were based on the high-end daily breathing rate of 393 L/kg body weight-day.

As shown above, a volume source that performs plasma spraying and uses products containing only 1 lb/yr of chromium could potentially result in cancer risks of up to 10 in a million for nearby receptors. The results from the other facilities also indicate that using small quantities of chromium can lead to cancer risks that exceed 10 in a million. To reduce the cancer risk from an uncontrolled operation, a facility would either need to install a control device or limit the usage of chromium-containing products to very low levels.

The results of the risk assessment indicate that a device which achieves 99.97% control efficiency will provide adequate control to keep potential cancer risks below 10 in a million, even if large quantities of chromium and nickel are used. The proposed ATCM is designed to ensure that potential cancer risk does not exceed 10 in a million for any thermal spraying facility that uses chromium or nickel.

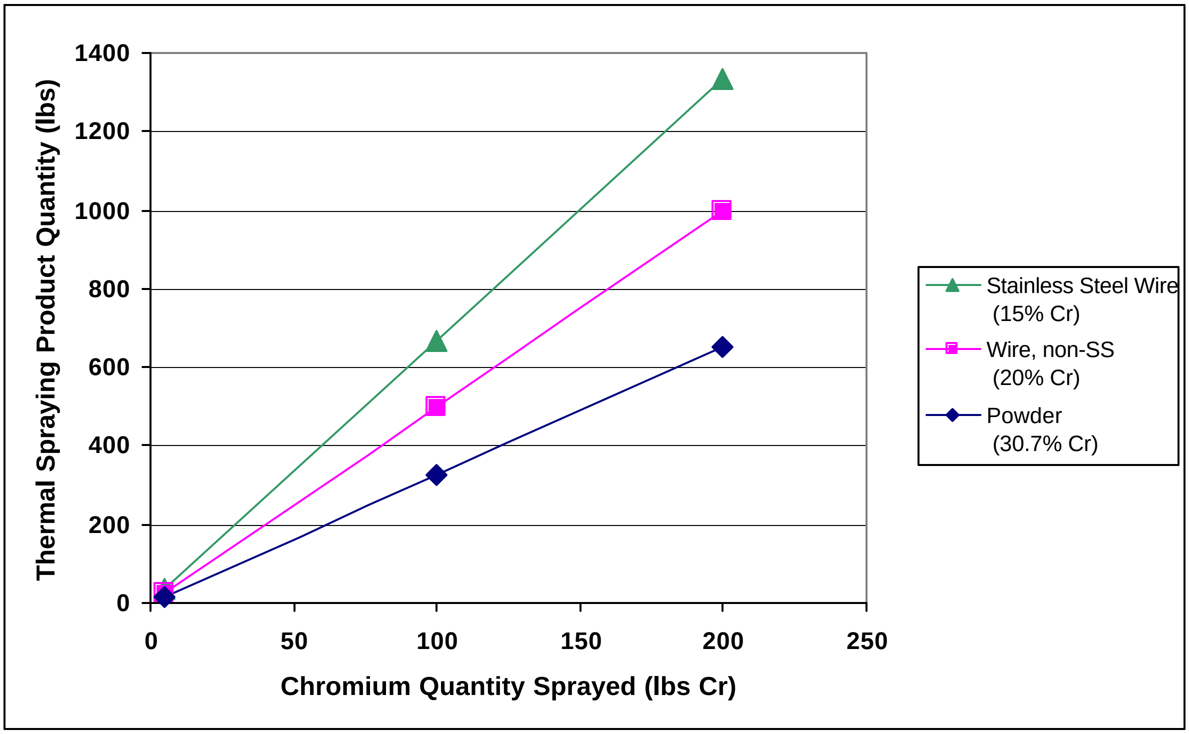
Emissions calculations and risk analyses were based on the quantity of pure chromium used. However, most shops use thermal spraying materials that contain only a percentage of chromium. Therefore, it's useful to provide a cross-reference for the amount of thermal spraying material that would correspond to a given amount of pure chromium. Table F-11 provides this information, based on the sales-weighted average chromium percentages from ARB's 2003 Thermal Spraying Materials Survey. Figure F-9 is a graphical cross-reference.

Table F-11:
Quantity of Pure Chromium in Thermal Spraying Products

This Quantity of Elemental Chromium (lbs Cr/yr):	Is equivalent to these amounts for thermal spraying products (lbs/yr):		
	Powder (30.7% Cr)	*Wire (non-stainless steel) (20% Cr)*	*Stainless Steel Wire (15% Cr)*
1	3	5	7
5	16	25	33
25	81	125	167
50	163	250	333
100	326	500	667

For example, spraying 25 pounds of chromium is equivalent to spraying 81 pounds of a typical thermal spraying powder (containing 30.7% of chromium).

Figure F-9:
Cross Reference: Chromium Usage & Corresponding Quantities of Typical Thermal Spraying Products



F.7. Non-Cancer Chronic Risk Characterization

Non-cancer chronic risk characterization involves estimating the maximum potential health impacts, based on long-term chronic exposure and reference exposure levels. Non-cancer health impacts are estimated by calculating a hazard quotient (single pollutant) or a hazard index (multiple pollutants). For the purposes of this risk assessment, we performed a multi-pathway risk assessment for non-cancer health impacts. Based on this analysis, we determined that the inhalation pathway and the potential impacts on the respiratory endpoint would present the most significant non-cancer chronic health impacts. Therefore, we determined the threshold emission rates that would likely result in a potential hazard index that does not exceed 1.0 for hexavalent chromium and nickel, based on the inhalation pathway only.

To estimate the non-cancer hazard indices from long-term chronic inhalation exposure, we used the following equation for each chemical, then added the impacts together when both chemicals impacted the same toxicological endpoint (e.g., the respiratory tract) (OEHHA, 2003):

$$\text{Eqn. F.8:}\quad [\text{Hazard Quotient}] = \frac{[\text{Annual Average Concentration, ug/m}^3]}{[\text{Chronic Reference Exposure Level, ug/m}^3]}$$

Annual average concentrations can be obtained from air dispersion modeling or they can be calculated (*[GLC] = [CHI/Q]*[Q]*). Table F-2 contains reference exposure levels (RELs).

For each of the facilities listed in Table F-3, we calculated the annual emissions that would likely result in a potential hazard index that does not exceed 1.0. Equation F.5 is generally used to evaluate the hazard quotient based on a given concentration. However, this equation can also be used to determine the emission rates that would likely result in a given hazard quotient. As shown below, Equation F.8 can be reorganized to calculate the emission rates that would likely result in a potential chronic hazard quotient that does not exceed 1.0.

$$[\text{Hazard Quotient}] = \frac{[\text{Annual Avg. Concn.}]}{[\text{Chronic REL}]} = \frac{\text{GLC}}{[\text{Chronic REL}]} = \frac{[\text{CHI/Q}]*[\text{Q}]}{[\text{Chronic REL}]}$$

Therefore, the emission rate that would likely result in a given hazard quotient is –

$$\text{Eqn. F.9:}\quad [\text{Q}] = \text{Avg. Emission Rate (g/s)} = \frac{[\text{Hazard Quotient}]*[\text{Chronic REL}]}{[\text{CHI/Q}]}$$

Our chronic risk analysis was based on the assumption that both hexavalent chromium and nickel could be emitted simultaneously. We determined the minimum emission rates that would likely result in a potential chronic hazard index that does not exceed 1.0 for hexavalent chromium and nickel combined.

For hexavalent chromium, the emission rates that would likely result in a chronic hazard quotient of up to 1.0 are much higher than the emission rates that would trigger the need for additional controls to protect against cancer risk. Therefore, the controls that would be required to protect against cancer impacts would keep emission rates well below the level that could result in chronic health impacts from either hexavalent chromium or nickel.

If nickel was the only pollutant being emitted, the emission rates that would likely result in a chronic hazard quotient of up to 1.0 are higher than the emission rates that would trigger the need for additional controls to protect against cancer risk. Therefore, the controls that would be required to protect against cancer impacts would keep emission rates below the level that could result in chronic health impacts.

Our analysis indicated that long-term exposure to hexavalent chromium and nickel emissions from a small number of high-use thermal spraying facilities could result in a chronic hazard index greater than one. All but a few of the thermal spraying facilities in the State are expected to have hazard indices less than one. The highest estimated hazard index for a specific thermal spraying facility was approximately two. The proposed ATCM is designed to ensure that the chronic hazard index does not exceed 1.0 for any thermal spraying facility that uses chromium or nickel.

F.8. Non-Cancer Acute Risk Characterization

Non-cancer acute risk characterization involves calculating the maximum potential health impacts, based on short-term acute exposure and reference exposure levels. Non-cancer acute impacts are estimated by calculating a hazard quotient (single pollutant) or a hazard index (multiple pollutants). For the purposes of this risk assessment, we determined the threshold emission rates that would likely result in a potential hazard quotient that does not exceed 1.0. Hexavalent chromium does not have an established acute reference exposure level. Therefore, our evaluation only included nickel.

To estimate the non-cancer health impacts from short-term acute inhalation exposure, we used the following equation (OEHHA, 2003):

$$\textit{Eqn. F.10:}\quad [\textit{Hazard Quotient}] = \frac{[\textit{Maximum Hourly Concentration, ug/m}^3]}{[\textit{Acute Reference Exposure Level, ug/m}^3]}$$

Maximum hourly concentrations can be obtained from air dispersion modeling. Table F-2 contains reference exposure levels (RELs).

For each of the facilities listed in Table F-3, we calculated the maximum hourly emissions that would likely result in a potential acute hazard quotient of up to 1.0. Equation F.5 is generally used to evaluate the hazard quotient based on a given concentration. However, this equation can also be used to determine the emission rates that would likely result in a given hazard quotient. As shown below, Equation F.8 can be reorganized to calculate the emission rates that would likely result in a potential chronic hazard quotient of up to 1.0.

$$[\textit{Hazard Quotient}] = \frac{[\textit{Max. Hourly Concn.}]}{[\textit{Acute REL}]} = \frac{[\textit{1-Hr GLC}]}{[\textit{Acute REL}]} = \frac{[\textit{Max. 1-Hr CHI/Q}]*[Q]}{[\textit{Acute REL}]}$$

Therefore, the emission rate that would likely result in a given hazard quotient is –

$$\textit{Eqn. F.11:}\quad [Q] = \textit{Emission Rate (g/s)} = \frac{[\textit{Hazard Quotient}]*[\textit{Acute REL}]}{[\textit{Max. 1-Hr CHI/Q}]}$$

For example, the emission rate that would likely result in a hazard quotient of up to 1.0, for a source that emits nickel, is calculated as shown below –

$$[Q], \textit{Emission Rate} = \frac{[1.0]^{*}\,[6.0\ ug/m^{3}]}{[333\ (ug/m^{3})/(g/s)]} = \frac{0.018\ grams}{sec} = \frac{\mathbf{0.14}\ lbs}{hour}$$

Table F-12 summarizes the key results from the acute risk analysis. It contains the minimum hourly emission rates that would likely result in potential acute hazard quotients that do not exceed 1.0. Table F-12 represents a conservative scenario for potential acute risks. Emissions from facilities that are located at different receptor distances may result in lower acute hazard quotients.

Table F-12:
Minimum Emission Rates That Would Likely Result in a Potential Acute Hazard Quotient Up To 1.0

Type of Source	**Receptor Distance Where Minimum Occurs (m)**	**Minimum Emission Rate (lbs/hour)**
		Nickel
Volume Source	22	0.01
Point Source	57	0.1

The primary non-cancer health impacts from thermal spraying are potential acute impacts from short-term exposure to nickel. Our analysis indicated that hourly nickel emissions from thermal spraying facilities could result in a hazard quotient that is greater than 1.0. The peak hourly nickel emission rates that would likely result in a potential acute hazard quotient of up to 1.0 are lower than the annual average hourly emission levels that would likely result in a potential cancer risk of up to 10 in a million or chronic hazard quotient of 1.0. Therefore, it is possible to have a potential acute hazard quotient that is greater than 1.0, even though the potential cancer risk from nickel is less than 10 in a million. For that reason, the proposed ATCM would include an hourly emission limit for nickel to protect against acute health risks. This hourly limit is designed to ensure that the acute hazard quotient does not exceed 1.0.

F.9. Workplace Exposure

Hexavalent chromium and nickel are human carcinogens. As such, the California Department of Industrial Relations, Division of Occupational Safety and Health Administration (Cal/OSHA) regulates these compounds in the workplace environment. To protect worker safety, Cal/OSHA has established permissible exposure limits (PEL) for these compounds. The PEL is the maximum, eight-hour, time-weighted average concentration for occupational exposure and is 0.01 mg/m^3 for hexavalent chromium and 0.1 mg/m^3 for nickel (CCR, 2002.) Since the proposed ATCM will require ventilation systems for certain uncontrolled facilities, worker exposure to hexavalent chromium and nickel from the use of these products will be reduced.

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